

# **A Controlled Arc Welding and Separation Processes for Carbon Nanotubes**

By

Jeannette Benavides, Ph.D. and Harry Shaw  
NASA/Goddard Space Flight Center  
Greenbelt, Maryland  
USA

# Carbon Nanotubes for Space

## PARTNERSHIPS

Carnegie-Mellon University- NASA/GRC

Thin-film microbatteries

Clemson University

Hybrid Si-nanotube devices

Michigan State University

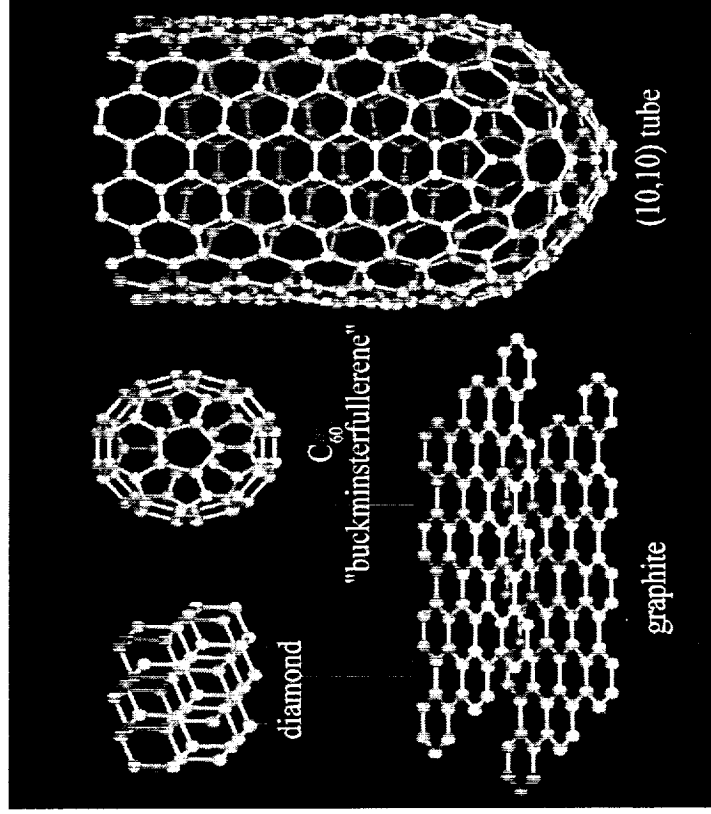
Advanced materials and basic properties

University of Pennsylvania

Radiation Effects and hybrid materials

NASA/Goddard

Synthesis and Applications



## BREAKTHROUGH

The GSFC Cooled Welding Method  
for the Synthesis of Carbon

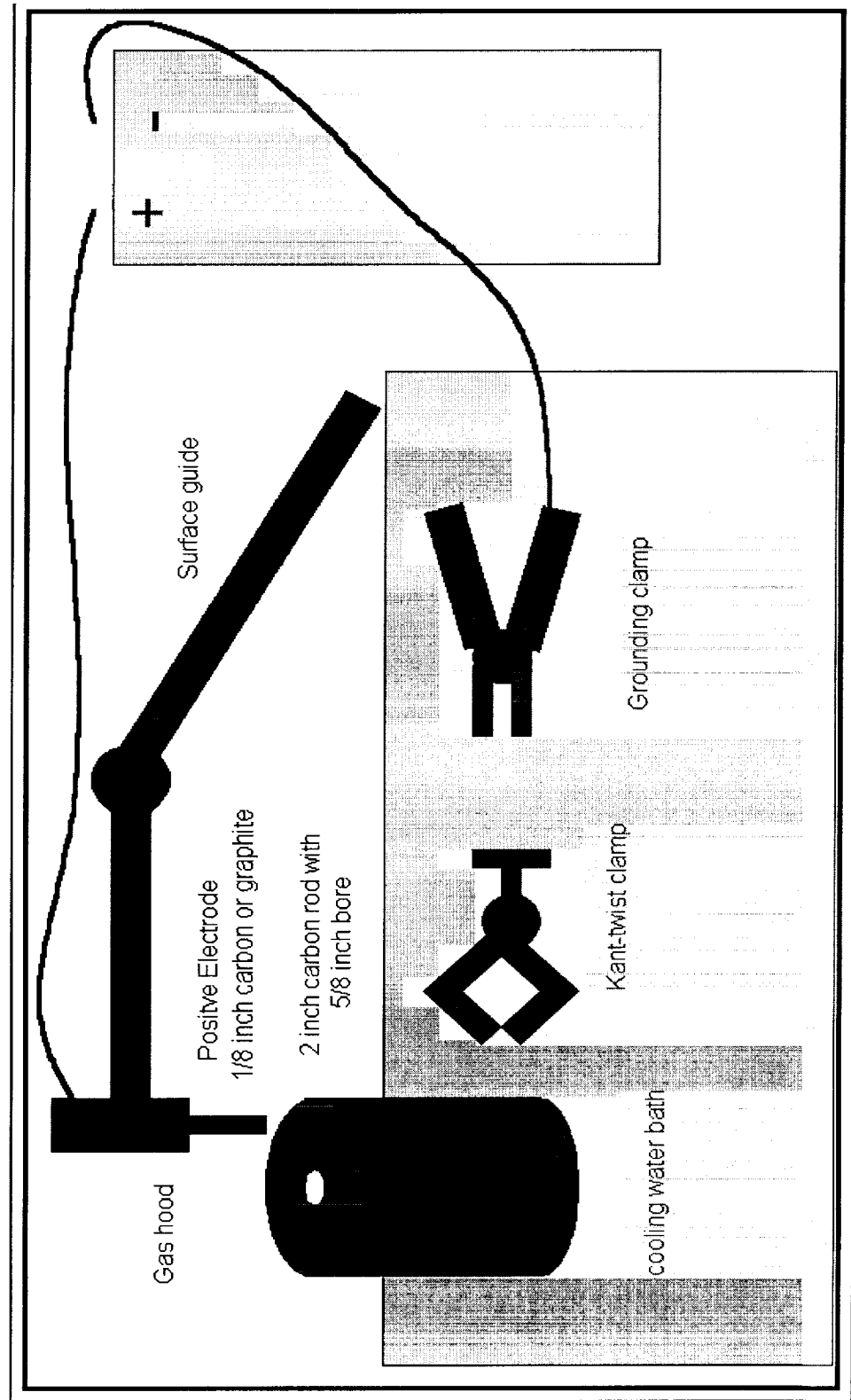
Nanotubes

Cost Effective

No Catalyst

Fast

# LAYOUT

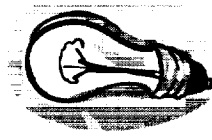


# Carbon Nanotube Project

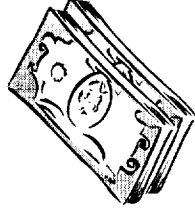


## STAGE I

(completed)



- Designed and Built System for Synthesis of CNT's
- Made 2g of SWNT's
- Characterized CNT's by XRD, TEM, SEM, DSC, EELS and Raman Spect.
- Designed Gradient Separation Method (currently being tested)



## STAGE 2

(this proposal)

- Produce CNT's Under Different Conditions such as Cooling Temperature, Voltage, Current, Cathode and Anode Sizes. Use Ferrocene to Make Longer CNT's
- Characterize CNT's by Spectroscopic Methods
- Develop Applications of CNT's, i.e. Batteries, Composites, Wires, etc.
- Complete Patent Application



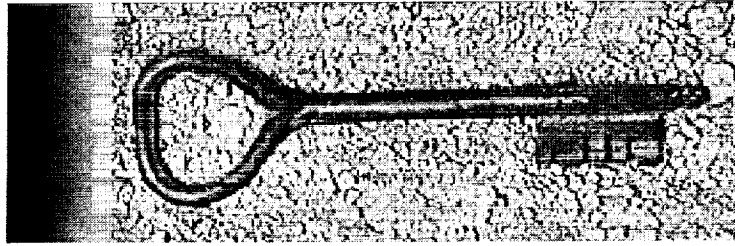
# Comparison with Hipco Process

• Yield	~ 30 %	• Yield	~60 %
• Press.	High	• Press.	Atm
• Temp.	1200°C	• Temp.	High short time
• Safety	Toxic Gases	• Safety	Non Toxic
• Catalyst	Iron	• catalyst	None
• Cost	1000/g	• Cost	~50/g
• Cleaning	Acid	• Cleaning	Gradient
• Decomposition	500°C	• Separation	
		• Decomposition	650°C

# CHARACTERIZATION

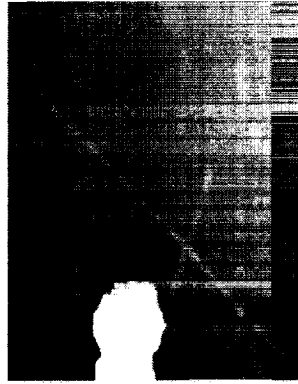
- SEM of SWCNT's at 50000X





# ATOMIC FORCE MICROSCOPE IMAGES OF CARBON NANOTUBES

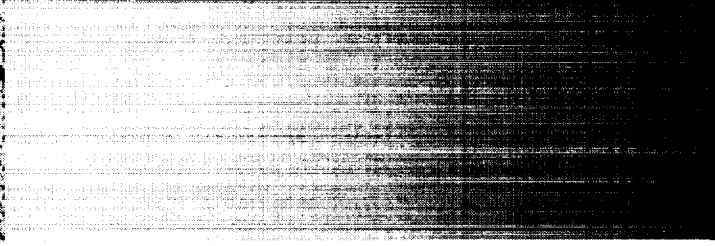
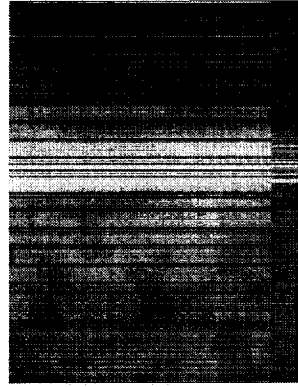
cnt#10.023

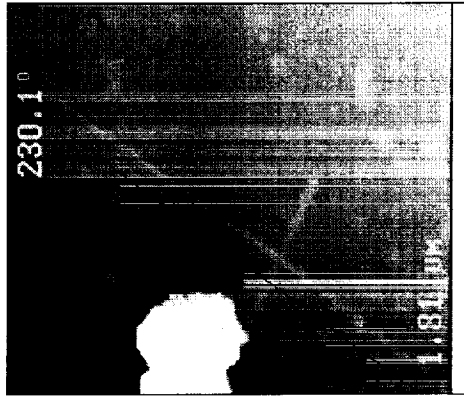
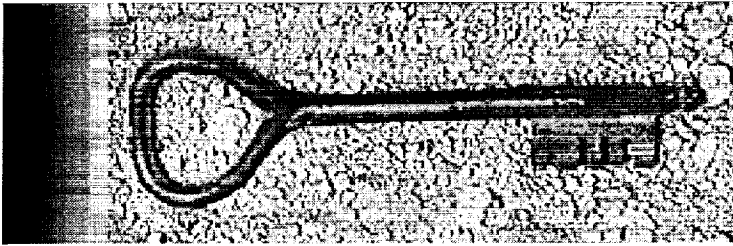


cnt#10.039

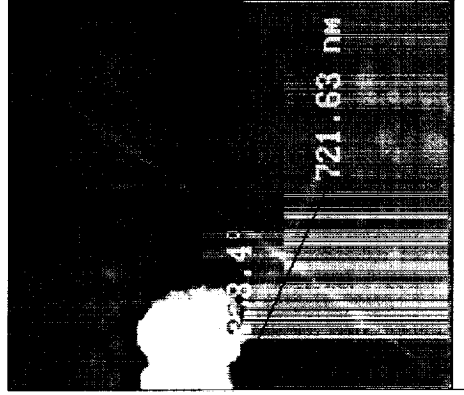


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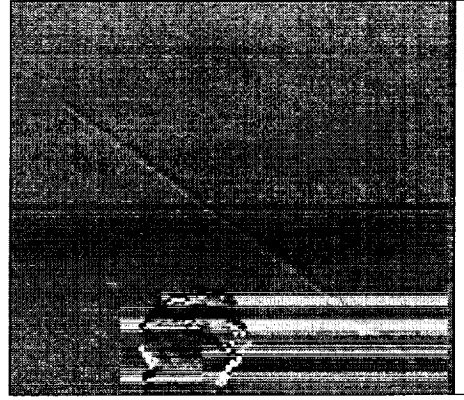




0 1.70  $\mu\text{m}$  Height  
Data type 150.0 nm  
Z range

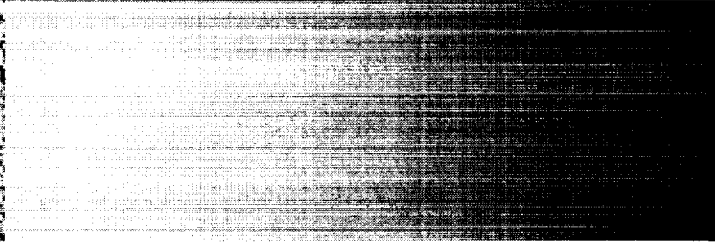
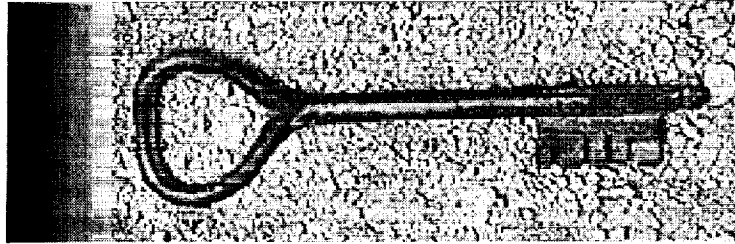


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Z range



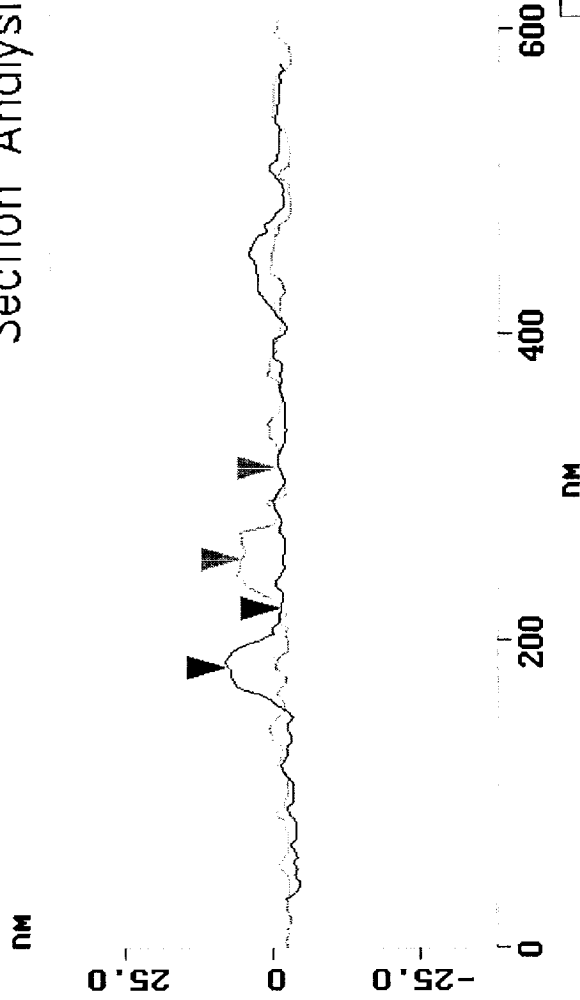
0 1.70  $\mu\text{m}$  Amplitude  
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Z range





Cursor Marker Spectrum Zoom Center Line Offset Clear

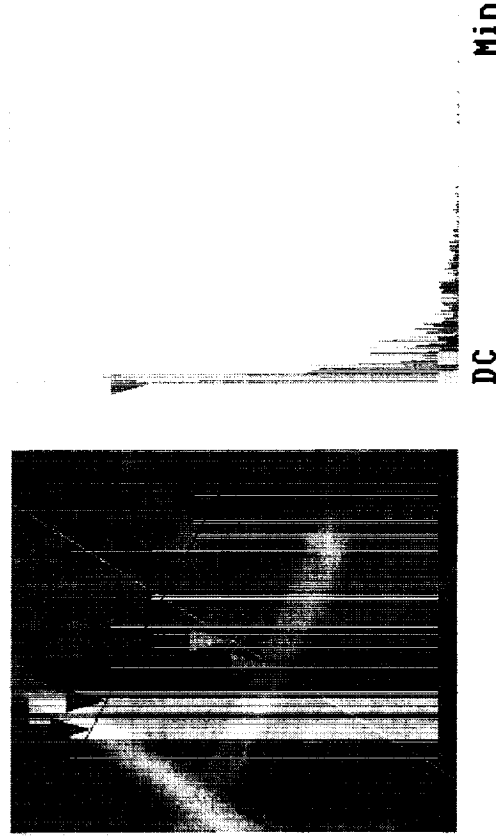
## Section Analysis



L	58.594 nm
RMS	2.976 nm
1c	DC
Ra(1c)	1.224 nm
Rmax	5.104 nm
Rz	3.489 nm
Rz Cnt	6
Radius	67.610 nm
Sigma	2.151 nm

Surface distance	41.413 nm
Horiz distance(L)	39.063 nm
Vert distance	8.425 nm
Angle	12.171 deg
Surface distance	53.232 nm
Horiz distance	58.594 nm
Vert distance	5.775 nm
Angle	5.629 deg
Surface distance	
Horiz distance	
Vert distance	
Angle	
Spectral period	DC
Spectral freq	0 Hz
Spectral RMS amp	0.668 nm

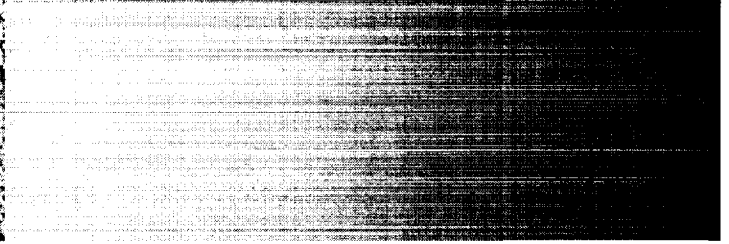
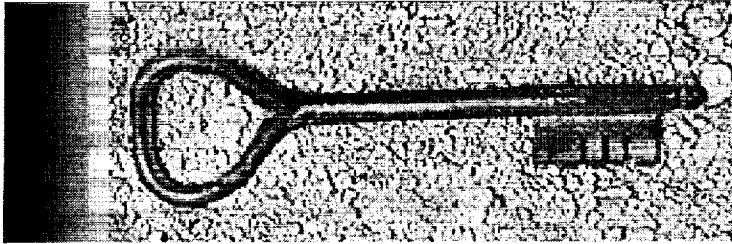
## Spectrum



cnt#10.039

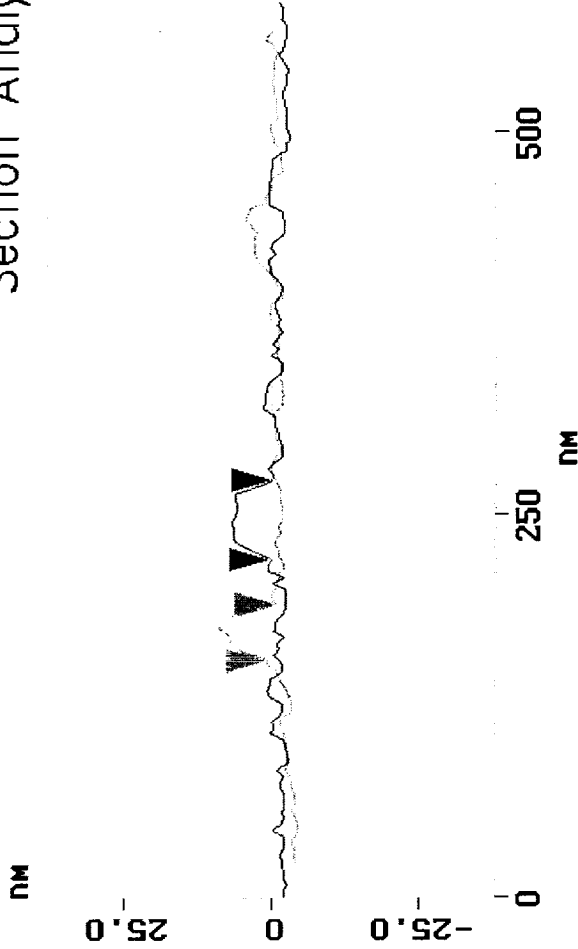
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cen line: off offset: off



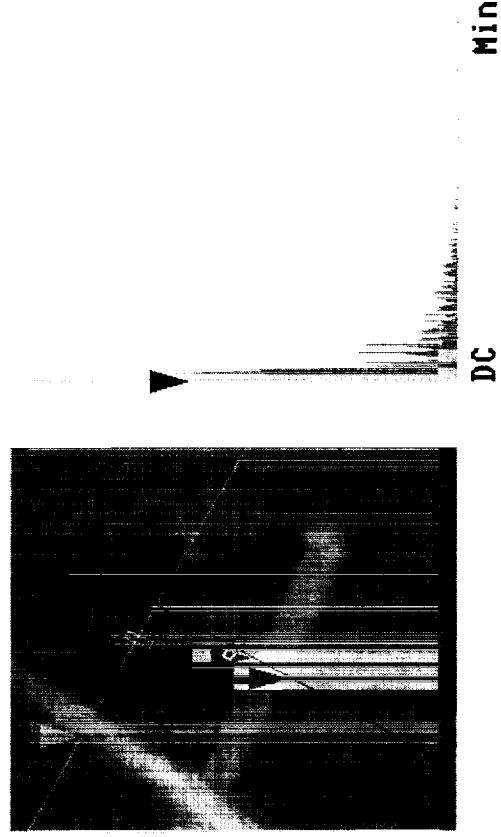
Cursor Marker Spectrum Zoom Center Line Offset Clear

## Section Analysis



L	50.781 nm
RMS	2.336 nm
Ic	DC
Ra(Ic)	1.592 nm
Rmax	6.996 nm
Rz	6.868 nm
Rz Cnt	2
Radius	48.388 nm
Sigma	0.780 nm

## Spectrum



Surface distance	54.538 nm
Horiz distance(L)	50.781 nm
Vert distance	0.189 nm
Angle	0.214 deg
Surface distance	40.916 nm
Horiz distance	35.156 nm
Vert distance	1.420 nm
Angle	2.313 deg
Surface distance	
Horiz distance	
Vert distance	
Angle	
Spectral period	DC
Spectral freq	0 Hz
Spectral RMS amp	0.671 nm

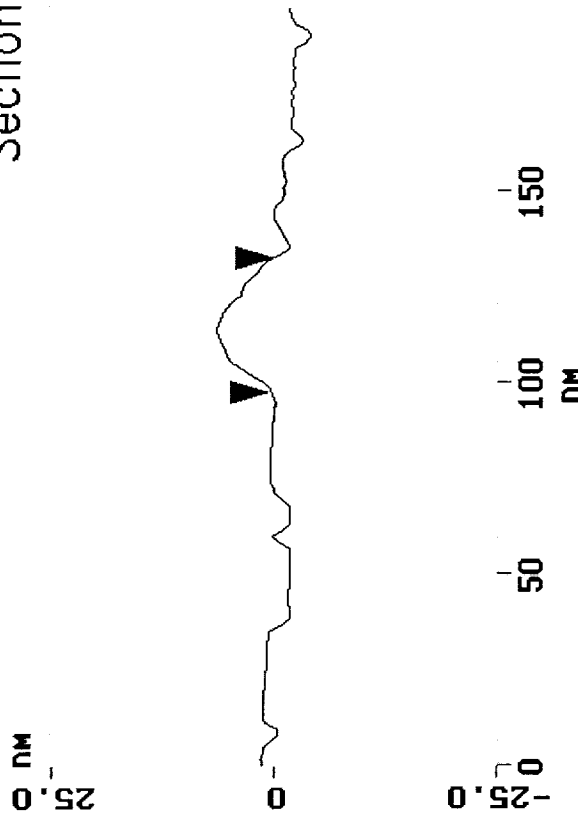
cnt#10.039

Cursor: fixed 2 Zoom: 2:1

Cen line: off Offset: off

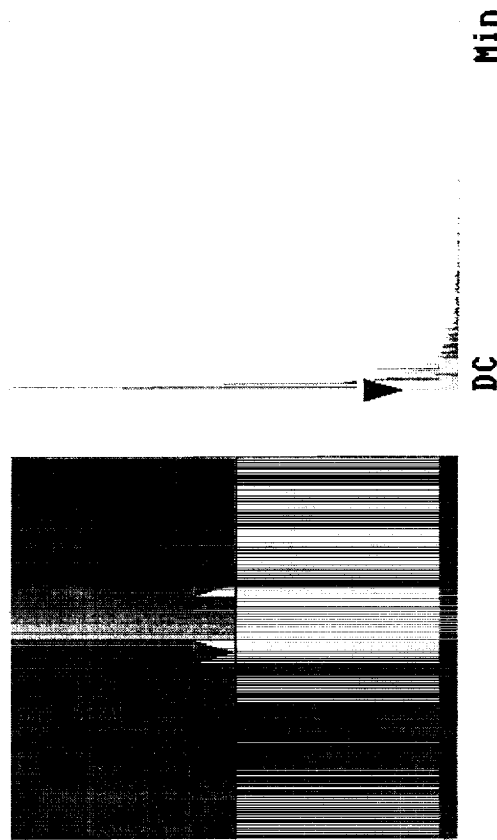
Cursor Marker Spectrum Zoom Center Line Offset Clear

## Section Analysis



L	35.938	NM
RMS	2.180	NM
Lc	DC	
Ra(Lc)	1.712	NM
Rmax	6.754	NM
Rz	6.754	NM
Rz Cnt 2		
Radius	26.785	NM
Sigma	0.425	NM

## Spectrum



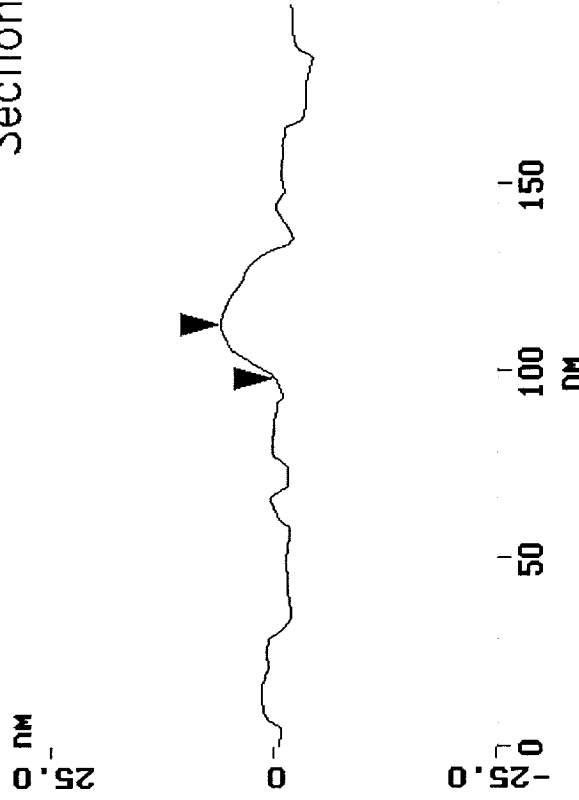
Surface distance	39.147	NM
Horiz distance(L)	35.938	NM
Vert distance	1.136	NM
Angle	1.811	deg
Surface distance		
Horiz distance		
Vert distance		
Angle		
Surface distance		
Horiz distance		
Vert distance		
Angle		
Spectral period	DC	
Spectral freq	0	Hz
Spectral RMS amp	0.185	NM

cnt#10.048

Cursor: fixed Zoom: 2:1 Cen line: off Offset: off

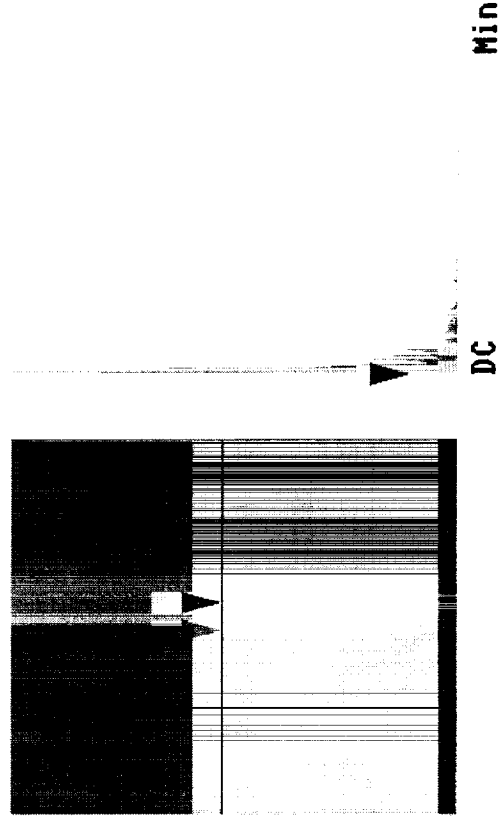
Cursor Marker Spectrum Zoom Center Line Offset Clear

## Section Analysis



L	15.625 nm
RMS	2.234 nm
Ic	DC
Ra(Ic)	0.495 nm
Rmax	2.209 nm
Rz	2.183 nm
Rz Cnt	2
Radius	20.793 nm
Sigma	0.218 nm

## Spectrum

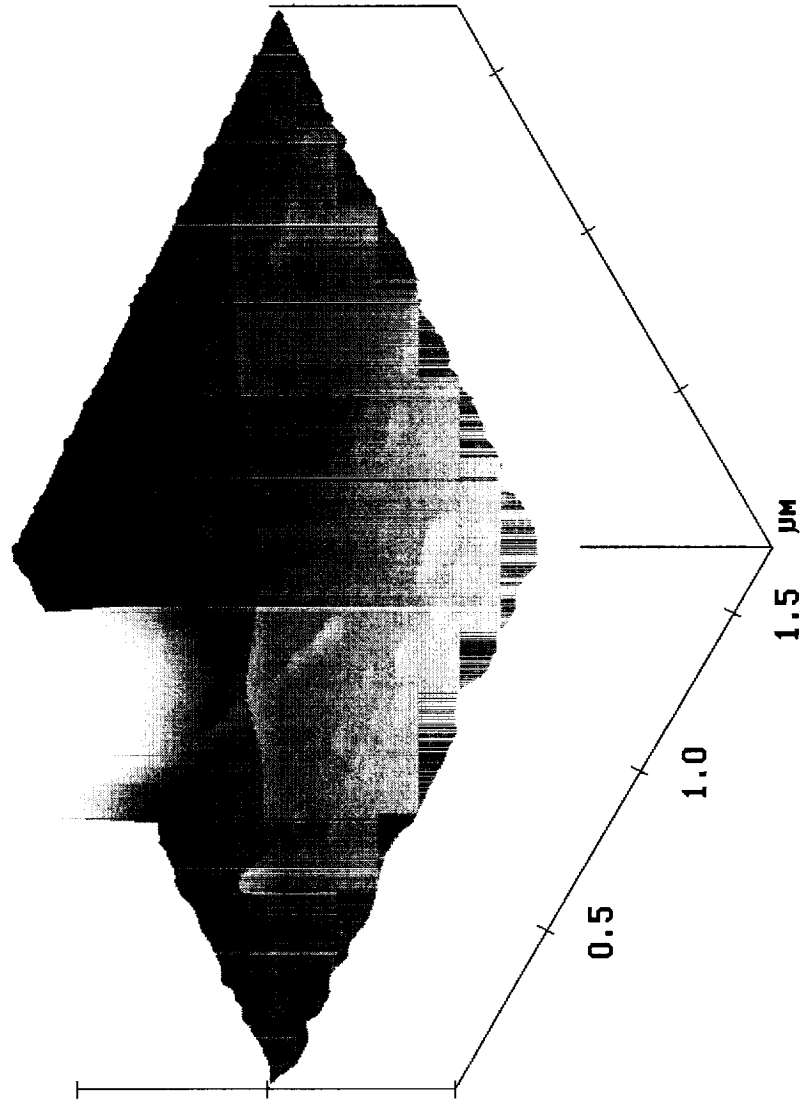


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Surface distance	17.313 nm
Horiz distance(L)	15.625 nm
Vert distance	6.342 nm
Angle	22.093 deg
Surface distance	
Horiz distance	
Vert distance	
Angle	
Surface distance	
Horiz distance	
Vert distance	
Angle	
Spectral period	DC
Spectral freq	0 Hz
Spectral RMS amp	0.157 nm

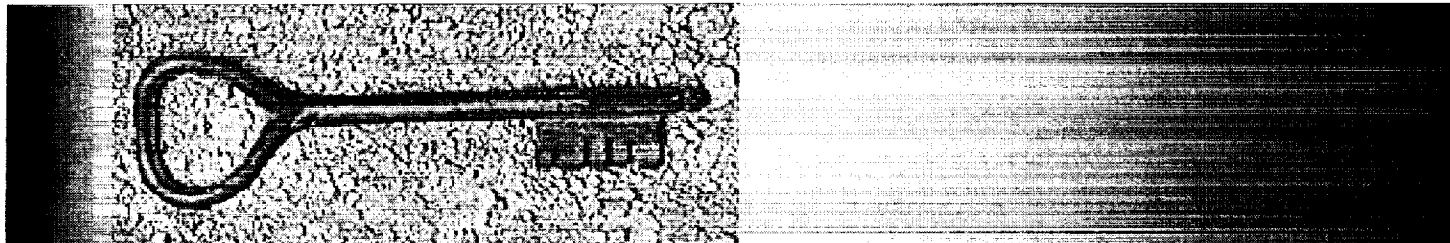
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Scan size 1.701  $\mu\text{m}$   
Scan rate 1.001 Hz  
Number of samples 128  
Image Data Height  
Data scale 150.0 nm

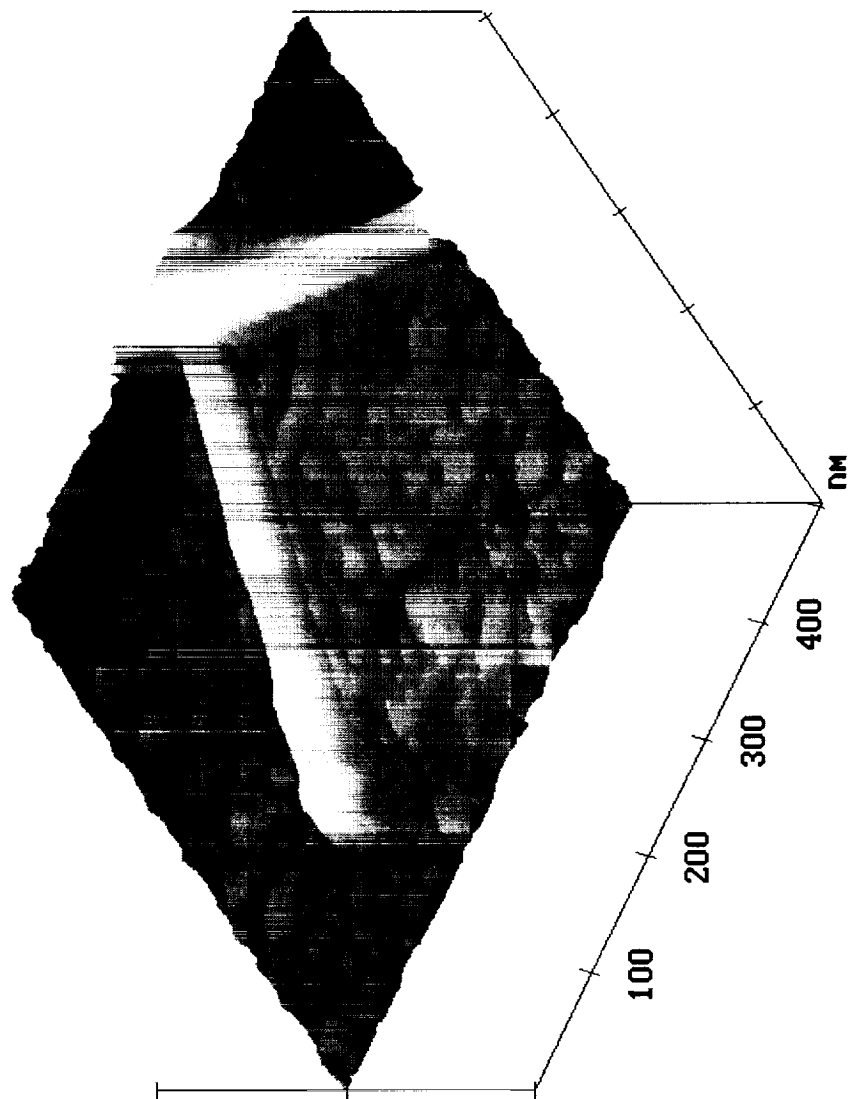


X 0.500  $\mu\text{m}/\text{div}$   
Z 150.000 nm/div

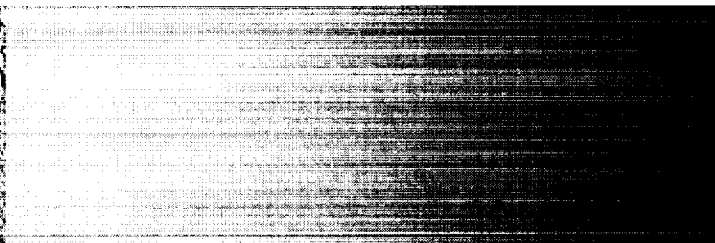
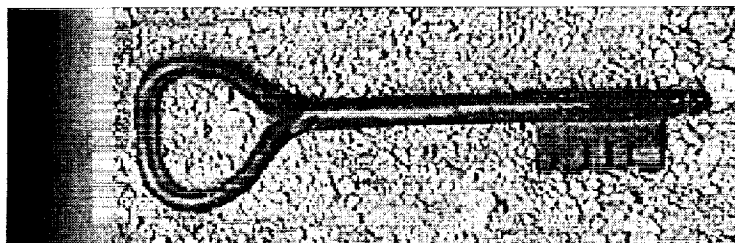
CNT #10



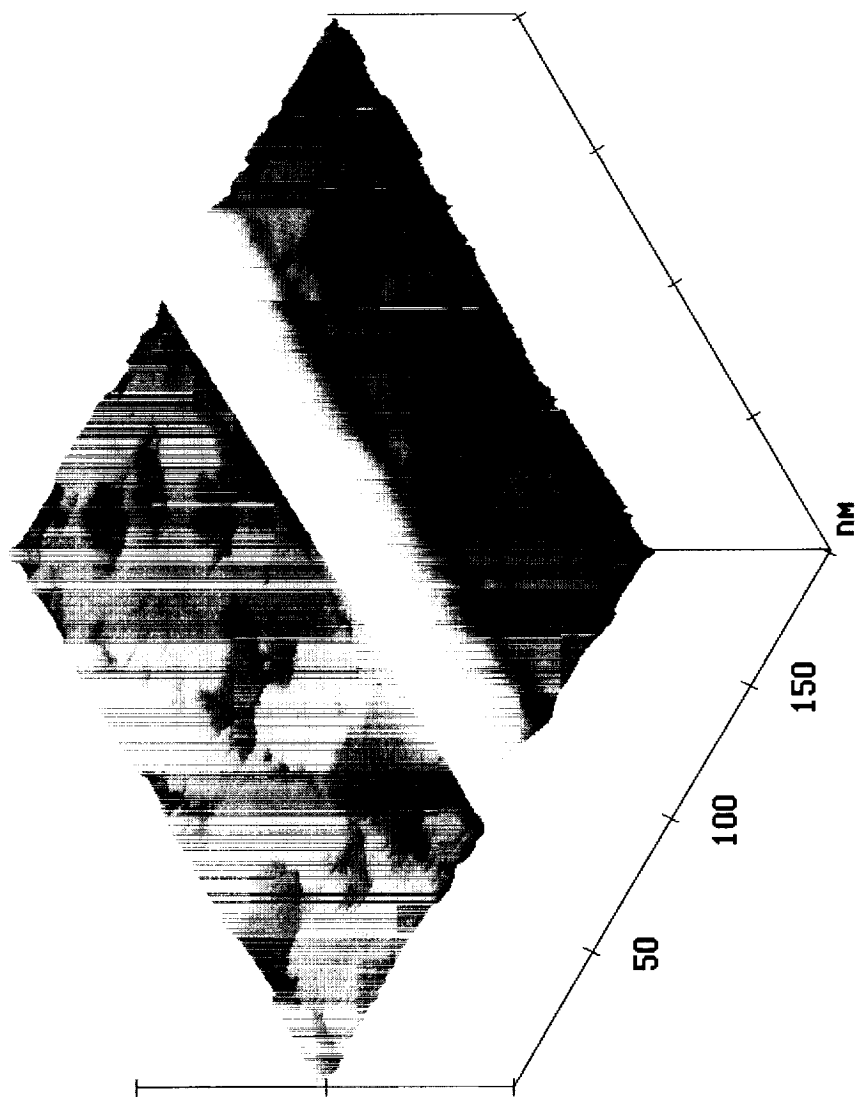
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Scan size 500.0 nm  
Scan rate 2.035 Hz  
Number of samples 128  
Image Data Height  
Data scale 75.00 nm



X 100.000 nm/div  
Z 75.000 nm/div

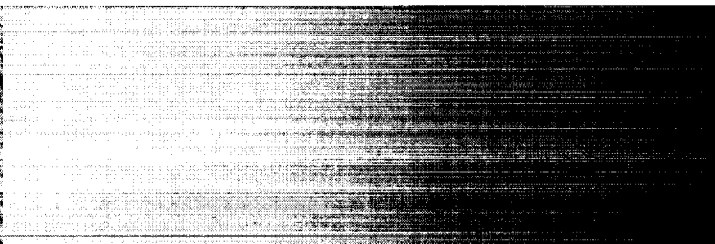
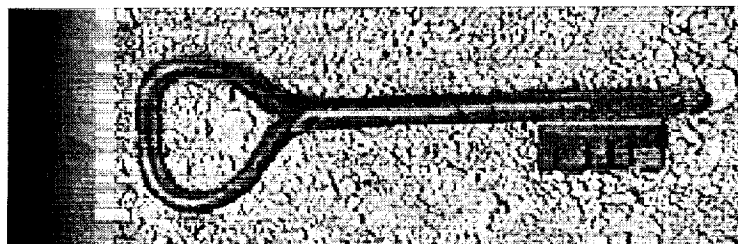


Digital Instruments NanoScope  
 Scan size 200.0 nm  
 Scan rate 1.001 Hz  
 Number of samples 128  
 Image Data Height  
 Data scale 50.00 nm



X 50.000 nm/div  
 Z 50.000 nm/div

CNT #10



# APPLICATIONS

- Molecule Manipulator and AFM Tips
- Nanowires, Switches
- Ropes
- Composites
- Drug Delivery
- Solar Sails
- Hydrogen Storage
- Micromachines (Functionalization)
- Microbatteries